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Lāna'i—A Case Study: The Loss of Biodiversity on a Small Hawaiian Island[1]

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ABSTRACT: Lāna'i, with only 361 km^2 of land area, is one of the smaller Hawaiian Islands. Its forest area is limited and its complement of flora and fauna is correspondingly low. Its relative isolation, however, has allowed development of a small but distinctive group of endemic plants, birds, insects, and molluscs. Throughout its period of human occupation it has suffered gradual losses in biodiversity due to the effects of grazing and browsing herbivores, aggressive introduced plants, predacious carnivores, diseases, and human activities. In recent years the loss of species has accelerated as Lāna'i's ecosystems have begun to suffer catastrophic collapse. This paper documents the changes that have occurred in historical chronology and predicts long-term results.

THE ISLAND OF LĀNA'I has always stood in the shadow of the larger Hawaiian Islands. Small and lacking abundant resources, especially water, it has never commanded the attentions and efforts of people to the degree the larger Islands have. But Lāna'i has a special blend of geology, geography, biological resources, and human history that offers an important perspective for land managers on the larger Hawaiian Islands.

Biodiversity in any given area is the result of the interaction of the area's biota with the components of the physical environment. It is the expression of the forces of adaptation and co-evolution on the flora and fauna over time resulting in a dynamic whole called an ecosystem. The status and stability of that biodiversity reflects the condition of the ecosystem. Its periodic assessment can thus be a valuable tool for land managers who are responsible for the viability of ecosystems under their jurisdiction.

The author has a special interest in Lāna'i. Having grown up there and having become interested in its biota and history at an early age, he has seen dramatic changes over the past four decades. Much of the information presented here comes from various geologists, historians, archaeologists, ranchers, and naturalists, the most notable of whom was George C. Munro, whose unpublished manuscript "The Story of Lanai" (in the Botany Library of the Bernice P. Bishop Museum, Honolulu) brings together many personal experiences and anecdotal accounts from earlier times that are not found elsewhere.

Physical Setting

Lāna'i is the sixth largest island in the Hawaiian Archipelago, with an area of 361 km^2 (89,280 acres) (Armstrong 1983). Created from a single volcano originating ca. 1.25 million yr ago, it presently rises to a height of 1027 m (3370 ft) with one summit ridge and a collapsed caldera basin forming an upland plateau (Stearns 1985). Lying to the lee of West Maui, it experiences a dry rainshadow effect, receiving less moisture than similar areas in Hawai'i with more exposure to the trade winds. Its maximum annual precipitation at the summit ridge is only 875 mm (35 in.), and its lower slopes are extremely arid, receiving less than 250 mm (10 in.) per year (Armstrong 1983).

Geologically, Lāna'i is part of the four-island complex comprising Maui, Moloka'i, Lāna'i, and Kaho'olawe, known collectively as Maui Nui (Greater Maui). During a – 106-

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LEGEND

1. Cloud Forest Community
2. Mesic Forest Community
3. Dry Forest Community
4. Arid Grassland and Shrubland Community
5. Coastal and Strand Community

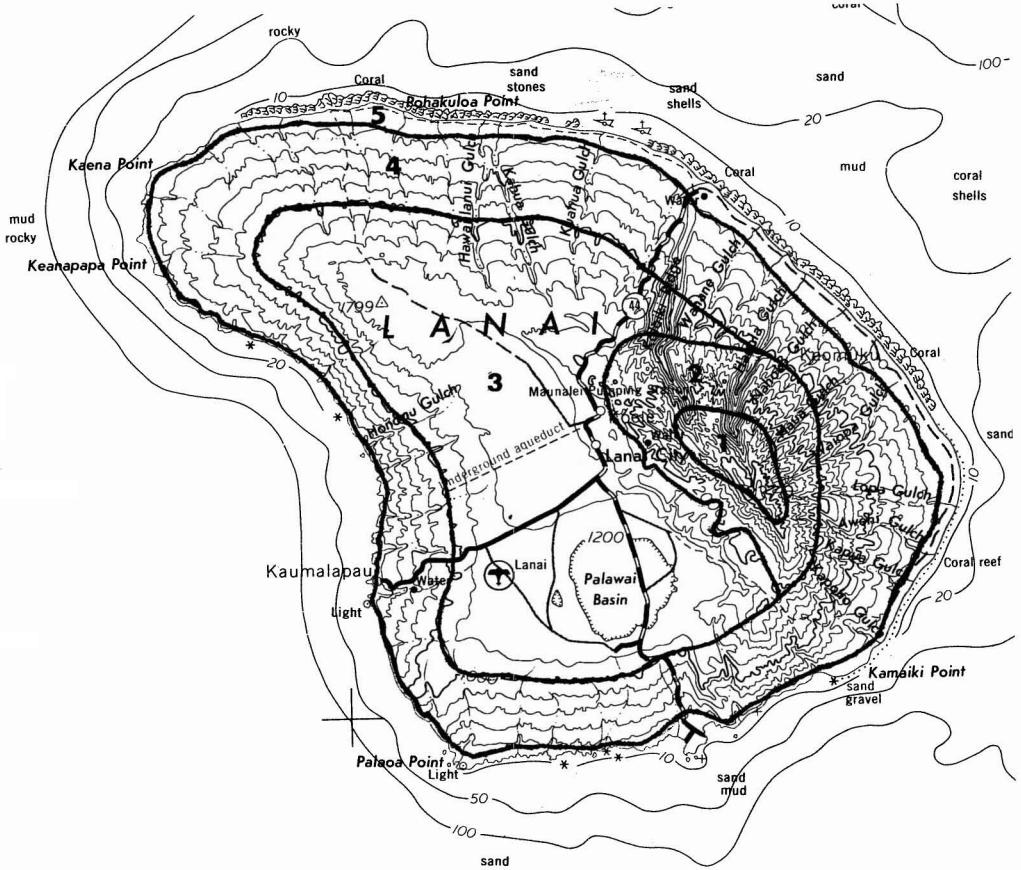

FIGURE 1. Pre-Polynesian vegetation communities on the island of Lāna'i.

m stand of the sea during the last Ice Age about 12,000 yr ago, these four islands were connected by a broad lowland plain (Stearns 1985). This landbridge allowed the movement and interaction of each island's flora and fauna and contributed to the present close relationships of their biota.

Native Vegetation

It is difficult to characterize accurately the flora and fauna of Lāna'i before the advent of the first Polynesian migrants around 1500 yr ago (Kirch 1974), but their subsequent alteration of the environment through slash and burn agriculture, hunting, and the gathering of forest products over the next 13 centuries created changes the magnitude of which we have only recently become aware (Olson and James 1982, 1991).

A general approximation of Lāna'i's vegetation before the effects of humans was reconstructed from information on early botanical collections, observations of existing relictual pockets of native vegetation, and the author's knowledge of Hawaiian ecosystems as they occur in various conditions throughout these Islands. To these elements can be added archaeological data and clues from Hawaiian legends and oral traditions. From this array of information five pre-Polynesian vegetation communities have been extrapolated (Figure 1, Table 1).

Within these vegetation communities, 345 species of vascular plants have been recorded including 259 angiosperms and 86 ferns (Wagner et al. 1990; Warren H. Wagner, Jr., and Florence S. Wagner, 1987, unpublished manuscript, "Revised Checklist and Keys to Hawaiian Pteridophytes," The Nature Conservancy of Hawai'i, Heritage Database, Honolulu). This amounts to 30% of all native Hawaiian vascular plant species. Eight of these species are endemic to the island of Lāna'i.

Sixteen species of native birds have been recorded from Lāna'i, including eight forest birds, one waterbird, one owl, and six resident seabirds (Berger 1972). This list does not include several nonresident seabirds and seasonal migrants. Of the resident birds, four species of forest birds, including three honeycreepers and one thrush, are endemic to Lāna'i.

At least 42 species of terrestrial molluscs are native to Lāna'i, scattered among 15 genera in nine families. Best represented are the cochlocopid genus *Leptachatina* (9), the

TABLE 1

EXTENT AND COMPOSITION OF PRE-POLYNESIAN VEGETATION COMMUNITIES ON LĀNA'I

VEGETATION COMMUNITIES	KM^2	% OF ISLAND	TOTAL ANNUAL MOISTURE	VEGETATION COMPONENTS
Cloud forest	7	2	875–1,250 mm* (35–50 in.)	Mixed *Metrosideros* forest with diverse fern understory
Mesic forest	25	7	675–875 mm (27–35 in.)	Diverse *Pouteria/Myrsine/Pisonia* forest with dense shrub/fern understory
Dry forest	130	36	500–675 mm (20–27 in.)	Diverse *Nestegis/Diospyros* or *Chamaesyce* forest with sparse shrub and liana understory
Arid grassland and shrubland	177	49	200–500 mm (8–20 in.)	*Heteropogon/Panicum* grassland or low *Dodonaea/Lipochaeta* shrub and forb community
Coastal and strand	22	6	200–450 mm (8–18 in.)	Mixed *Sida/Jacquemontia* herbland or *Gossypium/Sida* shrubland
Total	361			

*Recorded rainfall at the summit averages at about the lower end of this range. However, an unpublished fog-drip study conducted by the plantation indicated roughly a two-fold increase in realized precipitation under Cook pine trees and various devices designed to condense water from passing fog on summit ridgetops. Native forests on the summit ridges can also be observed condensing water on their leaves from wind-blown fog, although the level to which this augments Lāna'i's cloud forest rainfall is speculated here.

amastrid genera *Amastra* (12) and *Laminella* (3), the tornatellinid genus *Tornatellinides* (2), the achatinellid genus *Partulina* (3), and the helicarionid genus *Philonesia* (3) (Caum 1928; R. H. Cowie, unpublished checklist of the terrestrial mollusca of the Hawaiian Islands, in the Malacology Department of the Bernice P. Bishop Museum, Honolulu). Most of Lāna'i's land snails are island endemics primarily associated with forests of the upland plateau and summit ridge. The best land snail collections were made in the 1850s, 1870s, and 1890s (Pilsbry and Cooke 1908).

Lāna'i's insect fauna includes roughly 10% of the native species known to occur in Hawai'i. There are no good current summaries of Hawaiian insects available, but Lāna'i probably has in excess of 400 recorded species. Because of Lāna'i's proximity to other Islands and the relative mobility of many insects, only about 30% of these species are endemic to the Island. There are good representations of native Diptera, Lepidoptera, Hemiptera, Homoptera, Hymenoptera, and Coleoptera (Zimmerman 1948, Hardy 1965, 1981, Hardy and Delfinado 1980). Most species are very host-specific in their feeding and breeding requirements and form close interrelationships with their vegetation communities.

The First Hawaiians

We do not have accurate records of when the first Hawaiians came to Lāna'i. From oral traditions it seems that Lāna'i remained largely unpopulated for several hundred years because of its dry, inhospitable appearance and because it was supposed to have been inhabited by evil spirits (Fornander 1916–1920). Sometime around A.D. 1400 Hawaiians started moving to Lāna'i in substantial numbers. In 1921–1922 Emory identified 489 house sites on the Island (Emory 1924). These were located primarily along the coastlines, where fishing was the main livelihood, but there were also about 70 on the upland plateau, where dry farming for sweet potatoes occurred, and 13 in Maunalei Gulch, where there was enough running water for some taro culture. Emory's rough estimate of Lāna'i's peak population placed it somewhere between 3000 and 3250 persons. The availability of water was a constraint to the location and number of people living on Lāna'i, and its scarcity has always limited the overall population despite the fertility of its soil.

Each of the ancient house sites is characterized by a central firepit (*kapuahi*) where cooking was done and burning coals were maintained. These required a constant supply of firewood. Fire was also used to some extent to clear land for agriculture. Wood was used to construct the frames for the grass-thatched houses and for tools, implements, and weapons. The forest trees and the vegetation in general must have been cleared to some extent around villages over several generations.

Around A.D. 1675, according to oral traditions, there lived a kahuna named Kawelo who dwelled in the northern uplands at Ka'a. Kawelo was said to have safeguarded the fertility of the people's pigs and dogs by maintaining a perpetual bonfire at a promontory known as Keahikawelo (the fire of Kawelo) (Gibson 1873). This fire was kept burning for many years, and no doubt had a significant impact on the dry forest in the area. It is interesting that the worst example of erosion on the northern plateau today is located at that spot.

In 1778, just a few months before Captain James Cook's first visit to these Islands, Lāna'i was devastated by a raid by the warring king of Hawai'i, Kalaniopu'u, and his chief, Kamehameha, who was eventually to unite all the Hawaiian Islands. Kamehameha was about 25 yr old at the time (King 1785). Humiliated by a series of defeats at the hands of Kahekili, the king of Maui, Kalaniopu'u retaliated against Lāna'i, which was under Kahekili's control. His army descended on the relatively unprotected island and systematically slaughtered nearly the entire populace, ate all the food supplies and crops, and destroyed or burned all the houses and other improvements (Kamakau 1866). Munro (in his unpublished manuscript "The Story of Lanai") observed extensive charcoal deposits on the uplands of Paoma'i and Ka'a that he believed to be the result of their scorched earth policy. Undoubtedly some of the extensive

erosion of this area began at this time. On the whole, though, the native vegetation of Lāna'i remained intact at the time of Cook's arrival.

The Arrival of Captain Cook

With Cook's arrival in the Hawaiian Islands in January 1778, a wave of cultural interaction and change began. Cook was killed at Kealakekua, Hawai'i, during his second visit to the Islands in January 1779. Lāna'i was first recorded in Western records by Cook's successor, Captain Charles Clerke, the following month while departing the Islands (King 1785). A number of other explorers visited the Hawaiian Islands over the next four decades, but the first documented visit by a Caucasian to Lāna'i was not made until 1823, when the Reverend William Ellis described the aspect of the island and some of its inhabitants (Ellis 1825).

During most of the early explorations of Hawai'i, the ship captains, in the course of giving gifts or trading with Hawaiian kings, brought various livestock to the Islands. Goats and European hogs were first brought in 1778, sheep in 1791, and cattle in 1793 (Tomich 1986). These animals, benefiting from the protection of the kings and lacking natural predators, flourished and spread widely, and within 30 yr were doing noticeable damage to native vegetation (Ellis 1825). Goats were brought to Lāna'i sometime in the early 1800s by Hawaiian residents and were soon herded in the lowlands as a source of meat (annecdotal accounts by Henry Gibson, in George C. Munro's unpublished manuscript, "The Story of Lanai."). During that period the goats destroyed the extensive, and by all accounts unique, forest of *'akoko* (*Chamaesyce celastroides* var. *lorifolia* [A. Gray] Degener & I Degener) that covered the upland basins of Pālāwai and Miki. These trees had a succulent bark with good quantities of moisture. The goats completely stripped off the bark, killing the trees. The goats did not penetrate the dense summit forests during those years as there was plenty to eat on the lower slopes and plateau.

Sometime in the mid-1800s sheep were brought to Lāna'i, probably in connection with the small colony of Mormons that had settled there in Pālāwai Basin. Later, under the management of Walter Murray Gibson, the decision was made to pursue the ranching of goats for skins and sheep for wool. In 1867 Gibson estimated that there were 18,000 goats and 10,000 sheep on the Island (Gibson 1867). In 1870 the botanist/physician Dr. William Hillebrand visited the Island with J. M. Lydgate. Lydgate described Lāna'i as "pretty well denuded of its forest cover" and observed that "only on the summit of the island ridge was there a somewhat moth-eaten mantle of it left, and only on the slopes of the higher ravines and the steep hillsides was that mantle really intact and undisturbed" (Lydgate 1920). In 1876 Gibson brought attention to the fact that "the isles are becoming naked at a fearful rate" and by 1898, when the Gibson family chapter on Lāna'i was coming to a close, it was estimated that there were nearly 50,000 sheep and a large but undetermined number of goats on the Island (Munro's unpublished manuscript, "The Story of Lanai"). They were running free over the Island because few fences had been constructed, and severe damage was being done. Native cover was stripped from most of the lowlands and central plateau, allowing advanced wind and water erosion to begin. The animals were pushing back the mesic forests and cloud forests of the main mountain ridge and denuding the middle-elevation canyonlands of the windward slope.

The Twentieth Century

In 1902 Charles Gay and his family moved to Lāna'i from Kaua'i and began a more controlled ranching operation focusing on cattle, with some experimental attempts at agriculture on the side. Gay's eldest son Lawrence recorded extensive accounts of life and conditions on Lāna'i during more than 20 yr on the Island (Gay 1965). He referred to an "era of destruction" to Lāna'i's native forests of the middle elevations and described extensive areas of "tree skeletons" on the northern plateau and in the central basin above 1000 ft [305 m] elevation. He also related how taro production in Maunalei Gulch had to be

discontinued in the late 1800s because numerous rocks were being dislodged by goats from the denuded cliffs above, threatening the lives of the farmers. The ensuing droughts resulting from the loss of forest cover had brought reduced productivity and famine to Lāna'i residents in the first decade of the twentieth century. The Island population, which stood at 2500 in 1823, had been reduced to less than 100 by 1902.

The Gays, alarmed at the condition of the island's forested watersheds, began extensive goat and sheep eradication efforts and started fencing the summit forest. In 1910 they invited Territorial Forester Ralph S. Hosmer to help them plan for the long-term recovery of the Island. Hosmer wrote a 27-page report recommending more fencing and animal eradication followed by tree and grass planting to speed the revegetation work on the lower slopes (Hosmer 1910).

In 1910 the Gays were forced to sell most of their Lāna'i holdings. The new owners, a group of bankers, formed the Lanai Company and hired former New Zealander George C. Munro in 1911 to run the ranch operation (Munro's unpublished manuscript, "The Story of Lanai"). Munro, who was both a rancher and an ornithologist, was a keen observer and documenter of the natural world, and an active conservationist. He became very knowledgeable about Lāna'i's native flora, birds, land snails, and insects as well as its history and Hawaiian culture. During his first decade on Lāna'i, while trying to establish a profitable cattle ranch and develop ground water supplies, he spent much of his time shooting great numbers of sheep and goats and was able to complete the fenceline around the mountain started by the Gays.

From his first days on Lāna'i, Munro carefully observed the native birds, and his notes are informative and insightful. Two forest birds, both Lāna'i endemics, the Lāna'i *'akialoa* (*Hemignathus obscurus lanaiensis* Rothschild) and the Lāna'i hook-billed finch (*Dysmorodrepanis munroi* Perkins), a monotypic member of a drepanidine genus that Munro discovered, were already quite rare when he arrived. Both birds, whose prime habitats had been in the now-vanished *'akoko* forests, had disappeared by 1920 (Munro 1960).

Under Munro's management the forests made a substantial recovery, a fact noted by Territorial Forester Charles S. Judd in a 1927 visit (Judd 1927) and later by F. Raymond Fosberg, who spent a week on the Island making plant collections (Fosberg 1936). Munro himself, during the same period, noted that the forest birds were likewise multiplying and he seemed optimistic about their future. In 1929, however, he noticed a sudden dramatic decline in numbers, and by 1931 three more species were gone from Lāna'i, followed by a fourth in 1937. These were the *'ō'ū* (*Psittirostra psittacea* Gmelin), the *'i'iwi* (*Vestiaria coccinea* Forster), and the last two remaining Lāna'i endemics, the Lāna'i creeper (*Paroreomyza montana montana* Wilson) and the Lāna'i thrush (*Myadestes lanaiensis lanaiensis* Wilson). By 1925 over 2000 laborers, including many immigrants, had moved to Lāna'i to work on the new pineapple plantation. These workers brought a considerable number of poultry and other birds with them, and Munro believed that there had been an inadvertent introduction of some avian disease that quickly spread throughout the small summit forest afflicting the native birds with a disease for which they had no defense (Munro 1960).

European hogs were introduced to Lāna'i in the late 1880s, but succumbed to a virulent hog cholera epidemic a few years later. A small piggery was started in 1911 at Waiapa'a on the slopes above the Pālāwai Basin. This endeavor was also unsuccessful because of the undependable water supply at that location. The remaining hogs were released and became feral. Munro, noticing signs of forest damage in the summit cloud forest as a result of their rooting, mounted an effort to rid the island of the hogs. In this he was successful, and by the mid-1930s they were eradicated (Munro's unpublished manuscript, "The Story of Lanai").

In 1941, 24.89 km^2 (6150 acres) that had been fenced by the ranch to protect the summit forest were set aside as the Maunalei Forest Reserve through a surrender agreement between the Hawaiian Pineapple Company and the Territorial Government. In 1948 George Munro, now retired, wrote a letter to Colin G. Lennox, the president of the Board of Agriculture and Forestry, seeking his as-

sistance in persuading Hawaiian Pineapple Company to additionally fence off the Kānepu'u dry forest to protect it from cattle and deer. He cited reductions in both forest extent and number of species. He recounted his long battle to get this forest fenced and protected and registered frustration that "all has been to no effect" (Department of Land and Natural Resources Files). During the 1950s several hectares of pine trees (*Pinus* spp.) were planted on the northern part of the summit to enhance fog drip, but little else in the way of forest management was initiated by the government or the Company during that period. In 1957 the Hawaiian Pineapple Company rescinded the surrender agreement, thereby terminating its forest reserve status (Department of Land and Natural Resources Files).

In 1920, 12 axis deer (*Axis axis* Erxleben) were brought to Lāna'i from Moloka'i (Cuddihy and Stone 1990). These multiplied in the Pālāwai Basin and were hunted for sport and meat. Munro was aware of the dangers to the forests of Lāna'i from this Indian species that dwells in forests in its native habitat, but felt that vigorous hunting pressure would keep it in check. Their numbers were still low at the time he retired from Lāna'i Company in 1937, but in reminiscences during the 1950s he regretted having recommended this introduction (Munro's unpublished manuscript, "The Story of Lanai").

George Munro introduced many species of plants to Lāna'i for erosion control and reforestation. These included molasses grass (*Melinis minutiflora* P. Beauv.), dallis grass (*Paspalum dilatatum* Poir.), guinea grass (*Panicum maximum* Jacq.), Australian saltbush (*Atriplex semibaccata* R. Br.), Cook pine (*Araucaria columnaris* [Forst. f.] Hook.), manuka (*Leptospermum scoparium* J. R. Forster & G. Forster), longleaf ironwood (*Casuarina glauca* Siebold ex Spreng.), firetree (*Myrica faya* Aiton), and several others. All of these species thrived and fulfilled the purposes for which they were planted. Several have done too well, choking out and replacing native species.

Other plant species have also become widespread and are crowding out native vegetation. Some of the most prominent are kiawe (*Prosopis pallida* [Humb. & Bonpl. ex Willd.] Kunth), Christmas berry (*Schinus terebinthifolius* Raddi), strawberry guava (*Psidium cattleianum* f. *lucidum* Degener), lantana (*Lantana camara* L.), haole koa (*Leucaena leucocephala* [Lam.] de Wit), balloon plant (*Asclepias physocarpa* [E. Mey.] Schlechter), and broomsedge (*Andropogon virginicus* L.).

Cattle ranching was discontinued as the Hawaiian Pineapple Company focused on pineapple cultivation, and cattle were completely gone from the Island by 1950. Mouflon sheep (*Ovis musimon* Pallas) and pronghorn antelope (*Antilocapra americana* Ord), however, were introduced to the Island as potential game animals in 1954 and 1960, respectively (Cuddihy and Stone 1990). The mouflon sheep multiplied and became common, but the pronghorn antelope, suffering from poaching and inadaptability to the foreign habitat, disappeared by 1982. During the 1950s and 1960s botanists Harold St. John and later Otto and Isa Degener explored Lāna'i in depth. Otto Degener recorded some of his findings and put forth a warning concerning the future of Lāna'i's native flora (Degener 1963). This was followed by a study that documented diminishing forest diversity at the Kānepu'u dry forest in 1971 (Spence and Montgomery 1976), and a report by the author in 1973 to the State Forester with similar information (Hobdy 1973). Both documents called for protective management including fencing, deer removal, and enrichment plantings of rare native species. During the 1970s Castle & Cooke, the parent company of the Hawaiian Pineapple Company, and State wildlife managers became concerned at the ever-dwindling expanse of forested watershed on the summit and decided to eradicate goats from the Island. This was accomplished through a concerted effort by 1981, and hopes were raised that the forest would once again recover. It was soon realized that this was not to be. Axis deer, relieved of competition from goats, quickly spread into the summit forests and windward canyonlands in a way that had not been anticipated. Their migration from the lowlands was apparently hastened by the loss of one of their prime food species, the haole koa, which was severely defoliated by a massive infestation of the Leucaena psyllid (*Heteropsylla cubana*

Crawford) beginning in 1984 (S. Montgomery, pers. comm.). The deer began to occupy and utilize canyon slopes and cliffs previously thought to be too steep for them. Also, their numbers steadily began to increase over a 10-yr period until by 1988 a government census estimated the population on the northern half of the Island alone to be over 3700 animals (Department of Land and Natural Resources Annual Game Census). Damage to the summit forests progressed alarmingly until increased public and private hunting programs began to reverse the population trend gradually.

Lāna'i Today

In 1992 Lāna'i's native flora and fauna are in a severely reduced state. The coastal and strand community has largely been destroyed. Small remnants, perhaps 3% of the original community, can be found along the east and south shores on sand dunes and raised limestone, but the bulk of this community has been taken over by *Prosopis* forest.

The arid grassland and shrubland community has been destroyed on the west and south sides of Lāna'i, but significant, if degraded, portions remain along the windward north and east slopes. About 20% of this community remains, although this figure is deceiving because much of the species diversity has been eliminated. Most of the community has been converted to non-native *Panicum/Chloris/Andropogon* grasslands with scattered *Leucaena* and *Lantana* shrub thickets.

Only about 2% of the dry forest community remains in small patches along the northern end of the plateau lands. This community has been largely replaced by pineapple cultivation. What is not cultivated is mostly *Melinis/Paspalum* grassland; *Casuarina*, *Lantana*, or *Shinus* forest; or barren ground.

About 3% of the mesic forest community remains in any semblance of a natural state. Small pockets occur in the upper 'Āwehi and Haua gulches, with most of the rest of the community converted to *Melinis* grassland, *Myrica* or *Psidium* forests, or barren, eroding canyonlands.

About 30% of the cloud forest community remains. This amounts to about 2 km^2 or roughly 200 ha (500 acres) of reasonably intact ecosystems within the upper gulches of the summit region. Most of the ridgetops are being covered with *Myrica*, *Psidium*, or *Leptospermum* thickets and many slopes are invaded by these species and *Melinis* grass as the deer make inroads and expose bare ground.

Only a small percentage of Lāna'i's original native vegetation remains. A few species dominate these remnants by virtue of their initial ubiquity or their resistance to the disturbances that have been brought to bear on them. Many of the less frequent to rare species have disappeared from the Island, some quite recently. Of the 345 recorded native vascular plants on Lāna'i, it appears that 70 (20%) have now disappeared from the Island. Three Lāna'i endemics, *Delissea sinuata* subsp. *lanaiensis* (Rock) Lammers, *Haplostachys munroi* C. Forbes, and *Hibiscadelphus crucibracteatus* Hobdy, are apparently extinct.

Most of Lāna'i's native land snails have disappeared. These highly specialized animals are particularly vulnerable to disruption of their habitat. Two species of *Partulina* remain, but their numbers are diminishing. An entire colony of *P. variabilis* Newcomb was observed to be destroyed in 1986 in a severely degraded mesic forest above Wawaeku. Numerous shells on the ground showed signs of rat predation. Moreover, the *Nestegis sandwicensis* (A. Gray) Degener, I. Degener & L. Johnson forest in which they had been living had been nearly replaced by thickets of *Psidium* and *Schinus*.

None of Lāna'i's native insect species have been documented as suffering extinction. They are, however, becoming increasingly difficult to find (S. Montgomery, pers. comm.), and the increasing rate of disturbance to native vegetation communities, especially in understory and ground litter levels, is undoubtedly placing severe strains on many species.

Since the last sighting of the *'amakihi* (*Hemignathus virens wilsoni* Rothschild) in 1976 (Hirai 1978), only one native forest bird survives in the summit forests today, the *'apapane* (*Himatione sanguinea sanguinea* Gmelin (Scott et al. 1986). The Hawaiian owl, *Asio flammeus*

sandwichensis Bloxam, is still fairly common because it has been able to adapt to a plentiful rodent population. Some seabirds still breed on Lāna'i, but mostly on inaccessible cliffs and offshore islets where cats, rats, and dogs can't disturb them.

Feral goats, sheep, and pigs no longer occur on the Island, but deer populations remain high and mouflon sheep are multiplying and expanding their range. Cats and rats remain important predators of native fauna.

The Future

The prognosis for Lāna'i's native flora and fauna is not good. The agents that have brought about the present levels of decline are for the most part still present and continue to exert their influence. No reversal or even significant abatement of the present trend appears likely. Lāna'i's native ecosystems have suffered severe disintegration of their many interactive components and are experiencing what may be termed catastrophic collapse. What it may be possible to save will probably amount to no more than assemblages of the more vigorous and resistant remnants. Too little remains of these ecosystems for them to effect significant recoveries. Erosion can be halted and reversed and revegetation promoted through the reduction of feral herbivores, but what comes back will not be dominated by native species.

Although Lāna'i has suffered less loss of biodiversity than the even-smaller islands of Kaho'olawe and Ni'ihau, its history and current status are more instructive. Lāna'i's ecosystems have been particularly vulnerable to the disturbances they have experienced because their small size makes any loss more immediately apparent. The larger Hawaiian Islands are less susceptible to this level of loss because of their more extensive native communities and their larger number of individual components. Nonetheless, a similar fate is not only possible on the larger Islands, it is already in process in many areas to greater or lesser degrees.

What has been experienced on Lāna'i should be held up as an example of cause and effect and of what can happen to island ecosystems. It is hoped that this example will stimulate increased levels of natural resource protection in Hawai'i because the priorities that are reflected in current resource management efforts will largely determine how much survives into the next century and beyond. How will history judge our custodianship?

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LITERATURE CITED

ARMSTRONG, R. WARWICK, ed. 1983. Atlas of Hawaii, 2d ed. University of Hawaii Press, Honolulu.

BERGER, ANDREW J. 1972. Hawaiian birdlife. University of Hawaii Press, Honolulu.

CAUM, E. L. 1928. Checklist of Hawaiian land and freshwater mollusca. Bernice P. Bishop Mus. Bull. 56:1–79.

CUDDIHY, LINDA W., and CHARLES P. STONE. 1990. Alteration of Native Hawaiian vegetation: Effects of humans, their activities and introductions. University of Hawaii Press, Honolulu.

DEGENER, OTTO. 1963. Botanist's expedition on Lanai. Hawaii. Bot. Soc. Newsl., pp. 107–108.

DEPARTMENT OF LAND AND NATURAL RESOURCES. 1907 through present. Files on Lanai. Wailuku, Maui.

———. 1976–1991. Annual game census and hunter success reports for the island of Lanai. Division of Forestry and Wildlife, Wailuku, Maui.

ELLIS, WILLIAM. 1825. Journal of a tour through Hawaii. Crocker and Brewster, Boston.

EMORY, KENNETH P. 1924. The island of Lanai: A survey of native culture. Bernice P. Bishop Mus. Bull. 12.

FORNANDER, ABRAHAM. 1916–1920. Collec-

tion of Hawaiian antiquities and folklore, vols. 4–6. Mem. B. P. Bishop Mus.

FOSBERG, F. RAYMOND. 1936. Plant collecting on Lanai, 1935. Mid-Pacific Mag., April–June, pp. 119–123.

GAY, LAWRENCE KAINOAHOU. 1965. True stories of the island of Lanai. Mission Press, The Advertiser Publishing Company, Honolulu.

GIBSON, WALTER M. 1867. Hawaiian Gazette, 5 January.

———. 1873. Keahikawelo. Nuhou. 13 May, Honolulu.

HARDY, D. ELMO. 1965. Insects of Hawaii, vol. 12. University of Hawaii Press, Honolulu.

———. 1981. Insects of Hawaii, vol. 14. University of Hawaii Press, Honolulu.

HARDY, D. ELMO, and MERCEDES D. DELFINADO. 1980. Insects of Hawaii, vol. 13. University of Hawaii Press, Honolulu.

HIRAI, LAWRENCE T. 1978. The native birds of Lanai, Hawaii. West. Birds 2171–2177.

HOBDY, ROBERT W. 1973. Lanai's dry native forest. A report to the State Forester, Division of Forestry, Wailuku.

HOSMER, RALPH S. 1910. A report on possibilities of forest work on the island of Lanai, Territory of Hawaii. Board of Agriculture and Forestry, Division of Forestry, Honolulu.

JUDD, CHARLES S. 1927. Hawaiian Forester and Agriculturist. January–March, p. 13.

KAMAKAU, S. M. 1866. Ka Moolelo o Kamehameha I. Ka Nupepa Kuokoa, vol. 5, no. 51, Honolulu.

KING, JAMES, 1785. A voyage to the Pacific Ocean [by Captain James Cook], 1776–1780, vol. 3, 2d ed. London.

KIRCH, PATRICK V. 1974. The chronology of early Hawaiian settlement. Archaeol. Phys. Anthropol. Oceania 9:110–119.

LYDGATE, J. M. 1920. Reminiscences of an amateur collector. Hawaiian Annual, p. 74.

MUNRO, GEORGE C. 1960. Birds of Hawaii. Charles E. Tuttle Co., Rutland, Vermont and Tokyo, Japan.

OLSON, STORRS L., and HELEN F. JAMES. 1982. Prodromus of the fossil avifauna of the Hawaiian Islands. Smithson. Contrib. Zool. 365.

———. 1991. Descriptions of thirty-two new species of birds from the Hawaiian Islands: Part I. Non-Passeriformes and Part II. Passeriformes. Ornithological Monographs Nos. 45 and 46, Department of Vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. American Ornithologists' Union, Washington, D.C.

PILSBRY, HENRY A., and C. MONTAGUE COOKE, JR. 1908. Notes on Hawaiian land shells. Occas. Pap. B. P. Bishop Museum 3(2): 1–22.

SCOTT, J. MICHAEL, STEPHEN MOUNTAINSPRING, FRED L. RAMSEY, and CAMERON B. KEPLER. 1986. Forest bird communities of the Hawaiian Islands: Their dynamics, ecology, and conservation. Studies in Avian Biology No. 9, Cooper Ornithological Society. Allen Press, Lawrence, Kansas.

SPENCE, GLEN E., and STEVEN L. MONTGOMERY. 1976. Ecology of the dryland forest at Kanepu'u, island of Lana'i. Hawaii. Bot. Soc. Newsl., pp. 62–80.

STEARNS, HAROLD T. 1985. Geology of the State of Hawaii, 2d ed. Pacific Books, Palo Alto, California.

TOMICH, QUENTIN P. 1986. Mammals in Hawaii: A synopsis and notational bibliography, 2d ed. Bishop Mus. Spec. Publ. 76, Bishop Museum Press, Honolulu.

WAGNER, WARREN L., DERRAL R. HERBST, and S. H. SOHMER. 1990. Manual of the flowering plants of Hawai'i. Bishop Museum Spec. Publ. 83, University of Hawaii Press, Bishop Museum Press. 2 vols.

ZIMMERMAN, ELWOOD C. 1948. Insects of Hawaii, vols. 1–11. University of Hawaii Press, Honolulu.